Electromagnetic Pulse Interaction and Coupling for the Army Multiple Systems Evaluation Program

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 Vul aust

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The level of dependence on interaction and coupling analysis for determining Army system vulnerability has increased proportionately with advances in the technical capability and the applicability of the analysis. Early system analysis programs relied heavily on system test data for inputs to damage analysis codes. Interaction and coupling analysis during the Pershing and Lance Missile System tests was limited to field definition

20. Abstract (Cont'd)

for the purpose of scaling the field test data and to investigations into the response of some basic problems, such as a vertical whip antenna and a two-wire line over an infinitely conducting ground plane.

Recent advances in the interaction and coupling areas under Army and Defense Nuclear Agency funded programs have made it possible for analytical response calculations to have a more direct role in the vulnerability assessments of Army systems. Presently, the Harry Diamond Laboratories is determining the vulnerability of 29 multichannel communications systems under the Army's Multiple Systems Evaluation Program (MSEP). Field testing of these systems has been required only for validation of analytical coupling models and circuit code models.

Three main computer codes have been applied to the coupling problems analyzed in the MSEP. These codes are "TEMPO," which contains up-to-date models of a variety of standard antennas along with a semiempirical technique for characterizing the response of more complex antennas; "NLINE," which treats multiconductor transmission lines; and "FREFLD," which is a transmission-line solution for the response of a coaxial cable. Typically, each of these codes depends on a specialized test or analysis technique to determine input parameters for the specific antenna or cable system under consideration.

This paper contains an overview of the three codes, showing the applications of the codes and techniques to particular system problems, along with the levels of confidence obtained.

FOREWORD

This paper presents an outline of the development of analytical tools and field testing for the analysis of nuclear electromagnetic pulse (EMP) interaction and coupling into tactical Army systems. A historical background is portrayed of the efforts of the Electromagnetic Effects Laboratory of the Harry Diamond Laboratories (previously a laboratory of the U.S. Army Mobility Equipment Research and Development Center). The advances both directly and through the guidance of technical contractors are documented in the references. This paper then brings the reader up to date on the current state of analysis in EMP interaction and coupling of tactical Army systems.

CONTENTS

FIGURES

1. INTRODUCTION

Interaction and coupling analysis has had an increasing role in recent Army systems electromagnetic pulse (EMP) vulnerability assessments. The level of reliance on predictive coupling tools has changed from simply providing confidence in system level tests to using, in all current Army assessments, predicted responses that rely on system level test comparisons for confidence. This fact may best be pointed out by reviewing early Army systems, their coupling problems, and the interaction and coupling work performed during these programs and comparing these with what is presently being accomplished under the Army's Multiple Systems Evaluation Program (MSEP).

2. PRIOR SYSTEMS

In the late 1960's and early 1970's, the Pershing Missile System and the Lance Missile System (fig. 1) were extensively tested[1-3]* and analyzed[4,5] for vulnerability to the high-altitude EMP threat. Although Pershing is much more complex than Lance, the coupling problems presented by the two missile systems were similar. Also, essentially the same testing and analysis philosophy was used in each assessment.
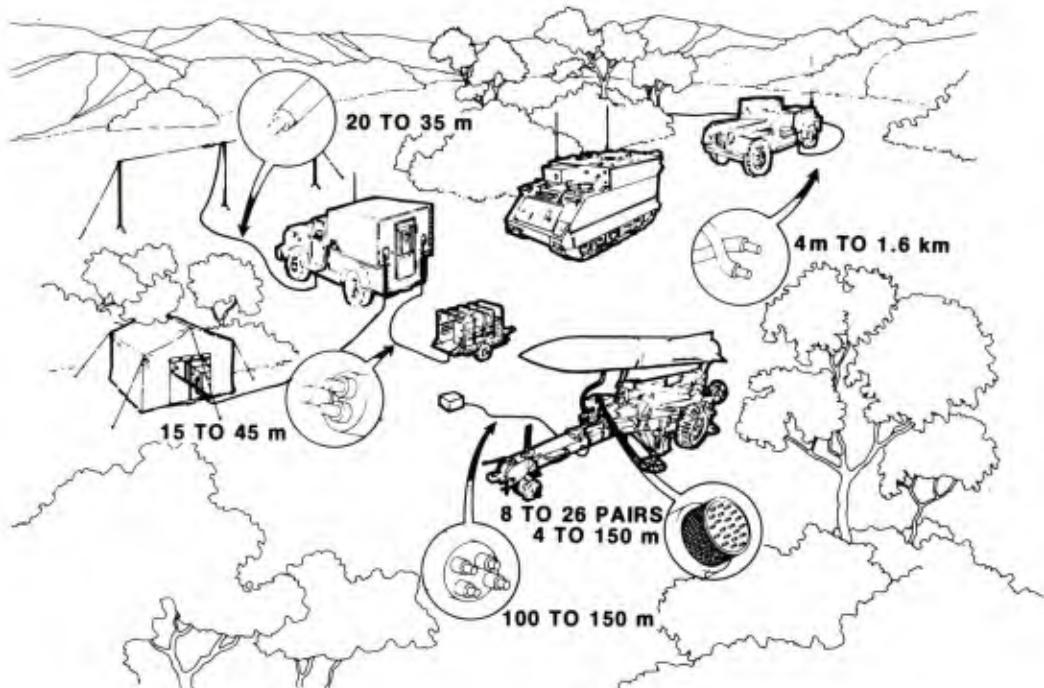

Figure 1. Lance Missile System.

Numbers refer to entries in the Literature Cited section.

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Various types of major coupling problems in these systems also are shown in figure 1. A variety of multiconductor cables appears in these systems. The multiconductor cables that had external shields ranged in size from 8 to 26 pairs of conductors and in length from 4 to 150 m. These cables are used to interconnect units mounted on the same chassis or other nearby vehicles and equipment. The unshielded multiconductor cables were typically used for power distribution and consisted of three or four conductors varying in length from 15 to 150 m.

The communication equipment associated with these systems employed simple whip antennas mounted on the signal shelters or vehicles and dipole antennas with coaxial feeds. The only land line used for communicaton is the WD-1/TT twisted pair of field wires which, for these systems, was limited to lengths of run up to 1.6 km. The twisted pair of field wires is the most commonly used cable in the Lance, and it is found in nearly all Army systems.

The vulnerability assessment of these systems relied heavily on extensive simulator testing to determine the response characteristics of the cables and the antennas. There were some initial attempts to modeling the coupling to single- and two-wire lines[6-9] and to some simple antennas[10] such as whips. Although these solutions were not used in the damage assessments of the systems, they added confidence to the measured system data that were used as input to the circuit analysis codes.[11,12]

Another major analytical effort during this period was defining the field output of the various simulators[13-18] used and comparing them with the output expected from a real threat.[19] In this way, the necessary scale factors for the system response data were determined.

In addition to the system testing being conducted at the time, many experiments were conducted on various simple coupling problems. These data proved useful in later code validation. Three computer codes that are being applied in present system studies were in their initial development stages during this period under funds provided by both the Army and the Defense Nuclear Agency. These codes are TEMPO, NLINE, and FREFLD.

3. PRESENT SYSTEMS

In recent years, the Army has been concentrating[20-24] on the communication equipment employed from the forward edge of the battle area back to the corps level (fig. 2). Some of the coupling problems associated with these systems are very similar to those encountered in the earlier missile systems. Essentially, the same power cabling and coaxial cable feeds for antennas are used in these systems along with the standard twisted pair of field wires.

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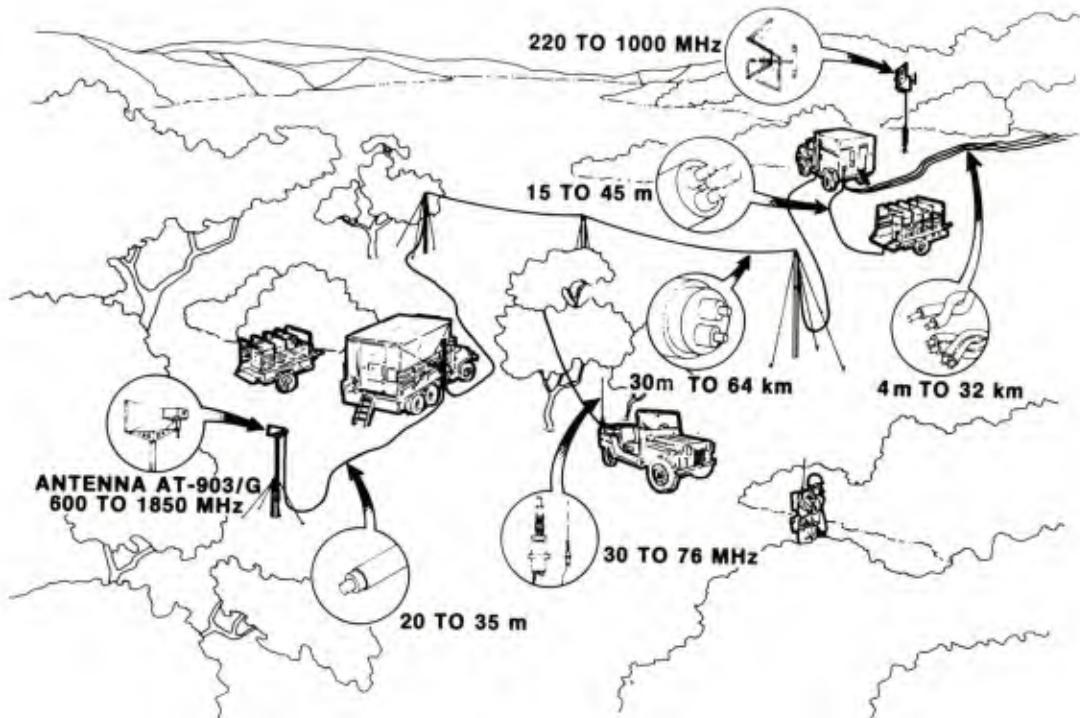
Figure 2. Typical Army communication equipment.

However, cable lengths and system terminations are more varied now. In addition to the standard twisted pair of field wires, a twisted four-wire telephone cable used with some of this equipment may also have lengths of runs up to 32 km.

Many of these systems have multichannel transmission capabilities either by radio link or through land lines. These land lines may be up to 64 km without a manned repeater, and the cabling may be deployed from ground level to a height of about 5 m. Unattended in-line repeaters are required every 1.6 km when long lengths of cable are used. This land line or pulse code modulation (PCM) cable consists of two coaxial cables, one for transmitting and one for receiving, which are twisted and covered by an overall braided shield.

Also, various antennas are used by this equipment. Some of the single-channel radios use a jeep-mounted center feed whip antenna, which has a preselector at the base of the antenna. The multichannel equipment uses more complex antennas, such as the horn antenna with a coaxial cable feed, which allows significant coupling to the system, and the dipole antenna with a corner reflector, which may be used with

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either vertically or horizontally polarized signals. The manpack portable AN/PRC-77 Radio Set (fig. 3) is probably the most common communication equipment in the Army. The AN/PRC-77 is a VHF-FM single channel radio that uses a variety of antennas ranging from a simple whip and a long-wire antenna to the fixed-site log-periodic unit.

ANTENNA EQUIPMENT RC-292

LOG-PERIODIC ANTENNA
AS-2169/G

0.9-m STEEL TAPE WHIP AT-892/PRC-25
3-m MULTISECTION WHIP AT-271/PRC
3-m VEHICULAR WHIP AT-912/VRC OR AS-1729/VRC
45-m LONG WIRE AT-984
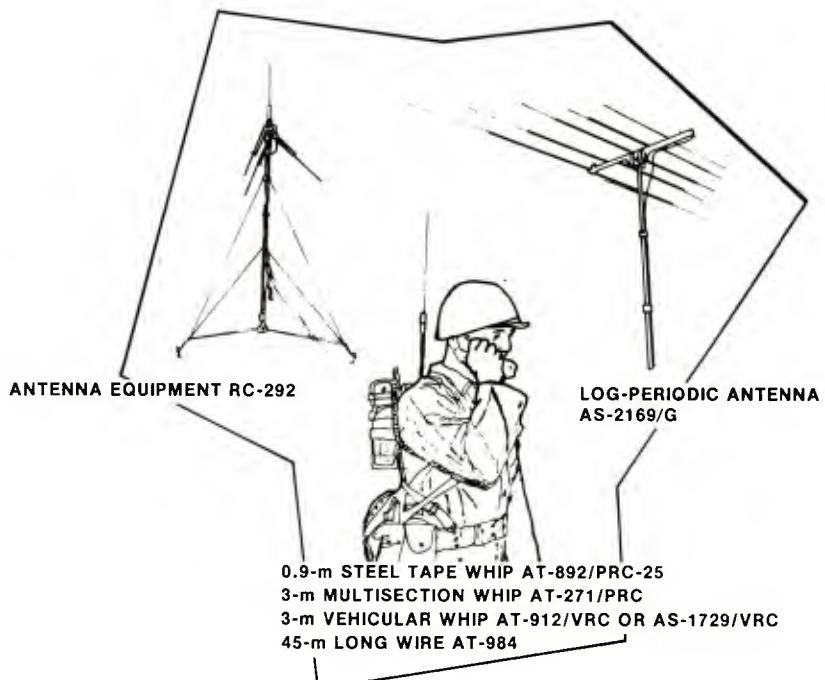
Figure 3. Manpack Portable Radio Set, AN/PRC-77 (30 to 76 MHz).

4. PRESENT ANALYSIS

Unlike the missile system assessments, the vulnerability assessments of this equipment have had a good balance between the experimental testing of the equipment with simulators and the use of analytical tools to determine the coupling response of the systems. Under the MSEP, a system vulnerability assessment has been developed that allows the approach taken to be tailored to meet the problems presented by the system under study: the Generic Assessment Method for a Priori Hardening Systems (GAMPHS) (fig. 4). The GAMPHS incorporates an up-to-date test data analysis based on the early assessments of Lance and Pershing along with an analytical technique for determining the responses of important coupling problems.
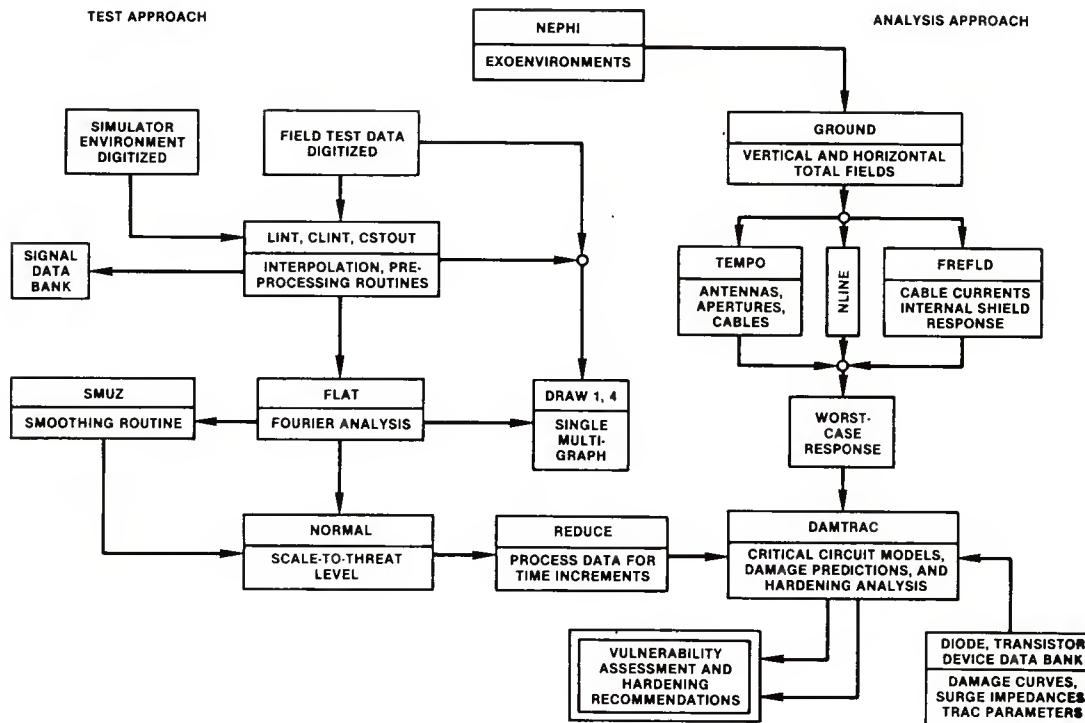
Figure 4. Generic Assessment Method for a Priori Hardening Systems in vulnerability and hardness assessment.

Three main computer codes have been applied to the coupling problems identified for these systems:

TEMPO[25] a compilation of analytical solutions for a variety of antennas plus a semiempirical technique of treating more complex antennas.

NLINE[26] a transmission line solution for EMP coupling with a lossless multiconductor transmission line located aboveground or in free space. This code can handle up to 11 conductors.

FREFLD[27] a transmission line solution for the external and internal responses of a coaxially shielded cable due to an arbitrarily oriented field.

Each of these codes is applied to a specific system coupling problem (fig. 5). The problem definition stage involves an investigation of the system and its various operational modes to define possible prime penetrations. Decisions are made in this stage as to what simulator

testing should be done on the system and what kind of analytical model should be used to treat each problem area. Each of these models requires a number of input parameters, both physical, such as cable length and height, and electrical, such as antenna impedance or shield transfer function. The determination of these electrical parameters typically involves the use of specialized test or analysis technique such as the Continuous Wave Test Facility[28] located at the Harry Diamond Laboratories Woodbridge Research Facility, which is used to determine the transfer function of complex antennas.
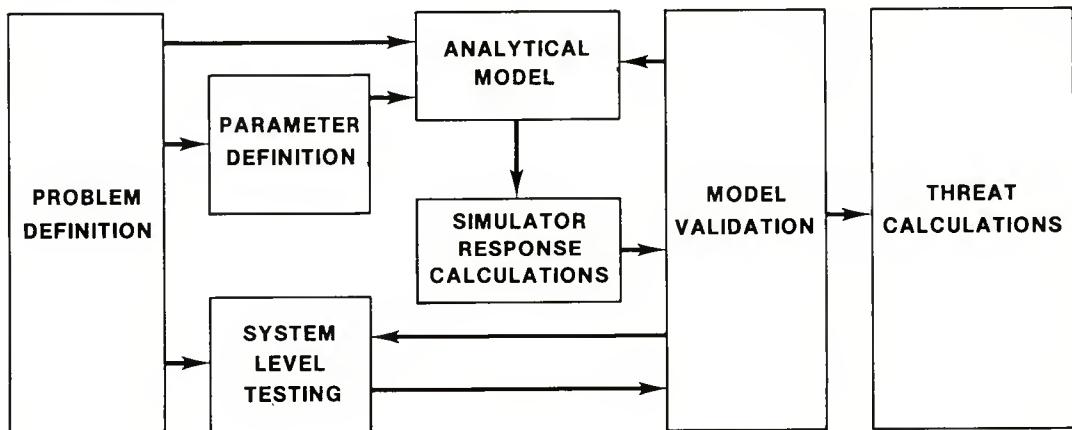
Figure 5. Preferred prediction method for applying interaction
and coupling codes to systems.

Once the necessary parameters are known and the specific conditions of the system level test are decided, a set of simulator response calculations is made, normally prior to system testing. A multiexponential curve fit of the simulator output is used in making the correlation calculations. An example of the accuracy obtainable with this type of curve fit is shown in figure 6 in both time and frequency domains. This type of field definition has the advantage of being easy to incorporate into analytical solutions working in either the time or the frequency domain, and it is accurate enough to allow good correlation of results.

The field test measurements and the simulator response calculations are then compared to determine the relative validity of the analytical model. Figure 5 shows the feedback from the validation stage to both the analytical model for modification of parameters, etc., and the field test area to allow for additional test conditions or for retesting to ensure accuracy.
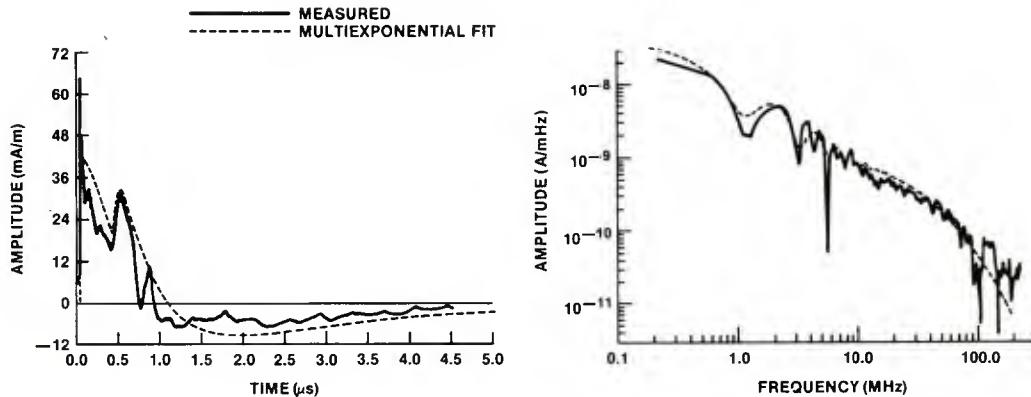
Figure 6.   Multiexponential curve fit comparison of radial magnetic
            field at 0, 200, and 0.5 m from Army EMP Simulator
            Operation (AESOP) simulator.

     Threat-level calculations are not made until the comparison between
the measured and calculated responses is satisfactory.   At times, this
desired level of confidence or validity is reached only after several
iterations through the calculation, measurement, and validation
stages.   In performing these cyclic comparisons, it is important to
validate many system configurations to ensure that the model is not
being tailored to satisfy only one system and simulator interaction
condition.   If this is not done, the model may not give the best
possible representation of the system for all of its obtainable
configurations.   Once the validity of the calculational technique has
been established, then threat levels are calculated for different field
illumination and system configurations to determine if a worst-case
response condition exists.   These worst-case response calculations are
then used in the system vulnerability analysis.

5.   VALIDATION PROCESS

   To demonstrate the levels of confidence obtainable with this
preferred prediction method of applying interaction and coupling codes
to systems and also to demonstrate some of the problems in its
application, the results of two validation efforts are presented here.
For continuity, both examples deal with the responses of a cable
connected to a system.   The same types of results are possible for
antennas.

The validation results for the first example, a simple one, are for the response of a 100-m length of field wire connected to a system via filters at the wire termination. A pretest calculation was made for the bulk or common mode current on the field wires by using only the known physical and electrical parameters of the cable and the system-to-earth termination. This pretest calculation and the measured response are given in figure 7. The correlation between the two responses is very good, and no refinement of the analytical model was necessary. The differential voltage response at the system is a much more difficult problem, and therefore its pretest calculated response did not fare nearly so well when compared with the measured response as did the bulk current calculations.
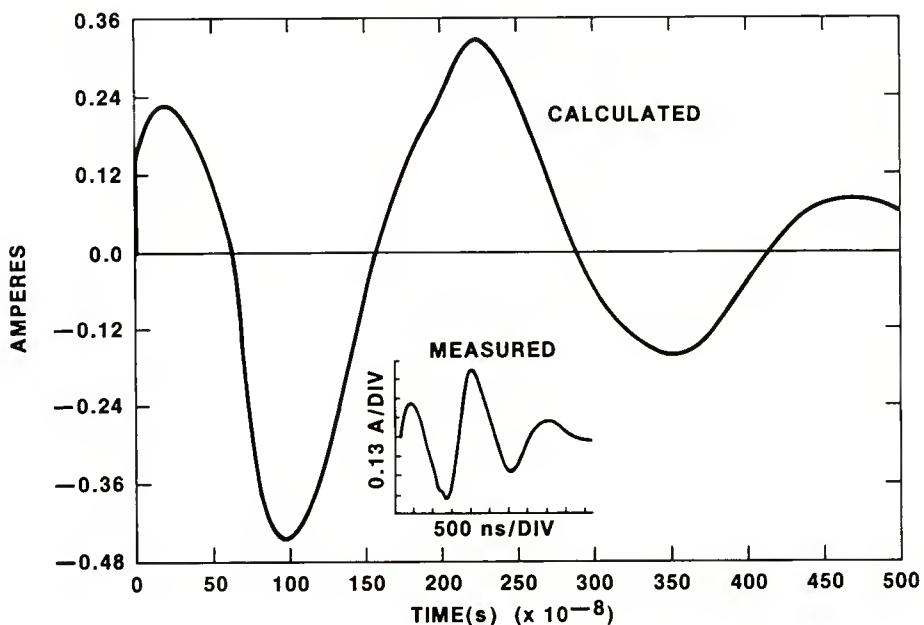
Figure 7. Validation result for simple system: 100-m field wire on ground with system termination on one end.

The validation results for the second example reflect a much more complex system employing the PCM cable (sect. 3) for the multichannel communication equipment AN/TRC-145 Radio Set (fig. 8). The Army EMP Simulator Operations (AESOP) simulator used during this test provided a wave shape corresponding to a horizontally polarized radiating dipole antenna. The AN/TRC-145 was tested 200 m from the AESOP on its center line. The AN/TRC-145 was connected to a remote unit by a 433-m length of PCM cable installed at a height of 4.6 m aboveground. Several other

cables connected the AN/TRC-145 to the test unit (fig. 8), and an ac generator with its ground rod was connected to each unit. All of the following response calculations and measurements were for the unit closest to the AESOP.
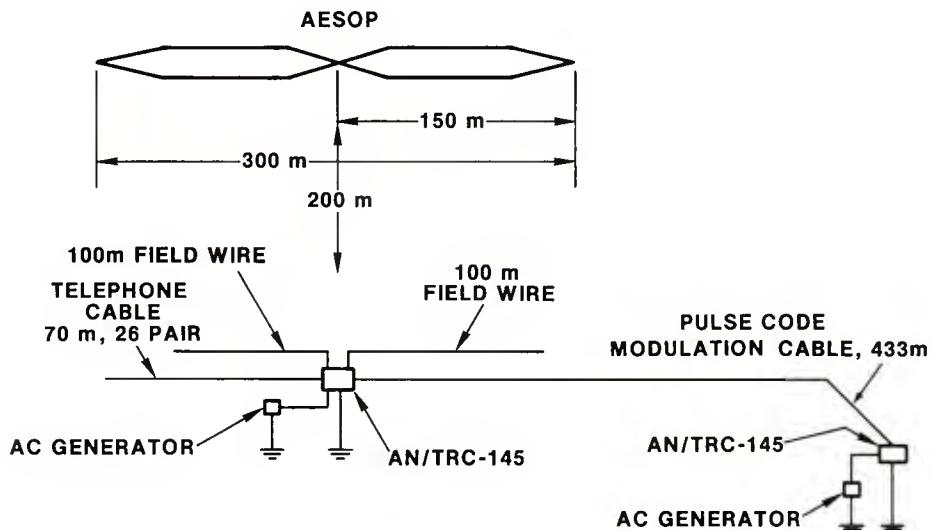
Figure 8. Configuration for Radio Set AN/TRC-145 field test.

The illumination of the PCM cable is far from planar. The peak field, the wave shape, the incidence angle, and the angle of orientation of the cable with respect to the horizontal electric field are functions of the position along the cable. Although the code applied to this problem can handle arbitrary orientations of the cable in the incident field, the field is assumed to be planar and of constant peak value and wave shape along the cable. Therefore, the pretest calculations for this problem consisted of a series of calculations for different angles of cable rotation in the field and of different field waveforms. The first cycle through the validation stage showed that several of the calculations would represent certain portions of the measured response. One calculation agreed well with the measured peak current, but agreed poorly with other characteristics of the measured data such as the time of arrival of the first reflection from the far unit or the late-time ring down. However, one of the other calculations agreed well with ring down, but agreed poorly with the peak amplitude.

Therefore, for the second validation example, the model was adjusted to obtain an average calculation, which was not necessarily the most accurate for any one item or portion of the response, but which best represented the overall measured system response. For the final validation results, figure 9 shows the external current response at the

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test unit, and figure 10 shows the internal current on both of the coaxial cable shields. The general characteristics of the two measurements are close to those of the calculated responses. However, the specifics such as peak amplitudes, which differ by factors of two or three at some points, are not nearly so accurate as were obtained for the first validation example.

Since these calculations required several iterations through the validation stage, some assurance was needed that the resulting model could be applied to conditions other than those used for the field test. Therefore, an additional set of field measurements was requested that used the same cable layout (which could not easily be reconfigured) due to the problems involved in accurately installing the cable for test. But the system-to-earth impedance was altered by removing the ac generators and, therefore, their grounds from the system. This terminating impedance change was accounted for in the analytical model, and the resulting comparison for the current on the inner coaxial cable shields is given in figure 11. In comparing the responses without the ac generator grounds to those in figure 10 with the grounds, one should note that both the calculated and the measured responses exhibit much greater damping of the late-time response. Although this new comparison does not offer definite proof that the model will retain the same level of confidence for all other configurations, it does contribute significantly to the overall confidence in the analytical representation of the system.
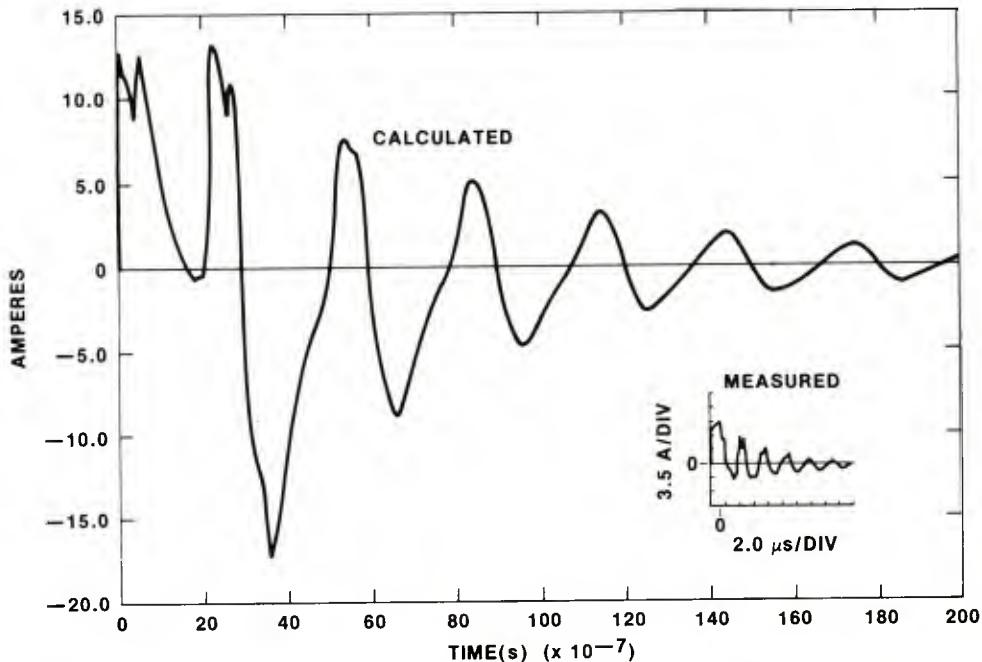
Figure 9. External cable current at test unit for Radio Set AN/TRC-145 pulse code modulation cable at 4.6 m with ac generator.

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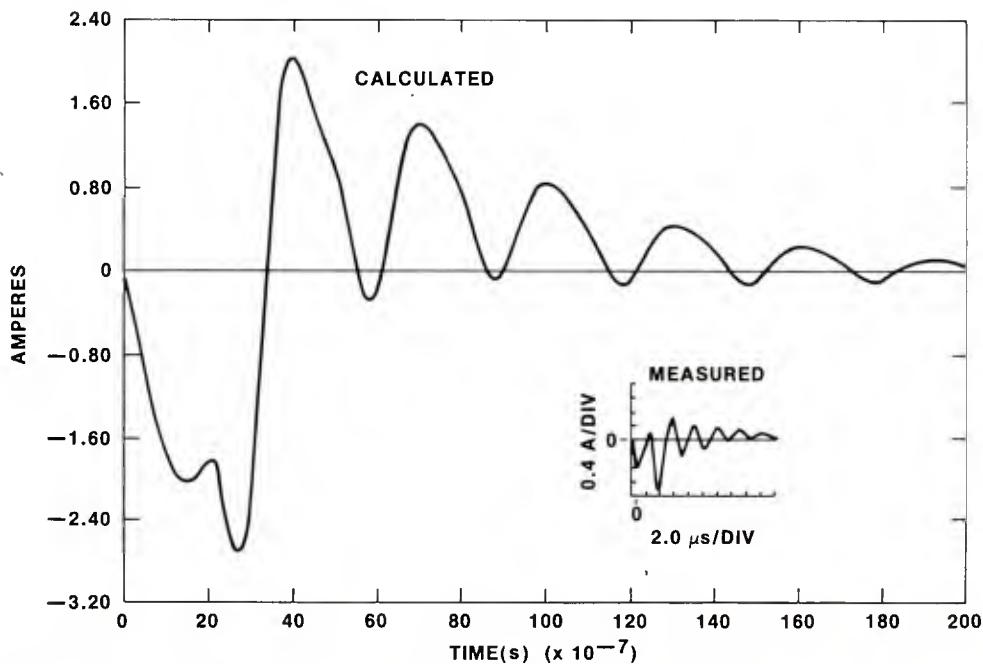
Figure 10.   Internal current on shields of coaxial cable pair for Radio Set AN/TRC-145 pulse code modulation cable at 4.6 m with ac generator.
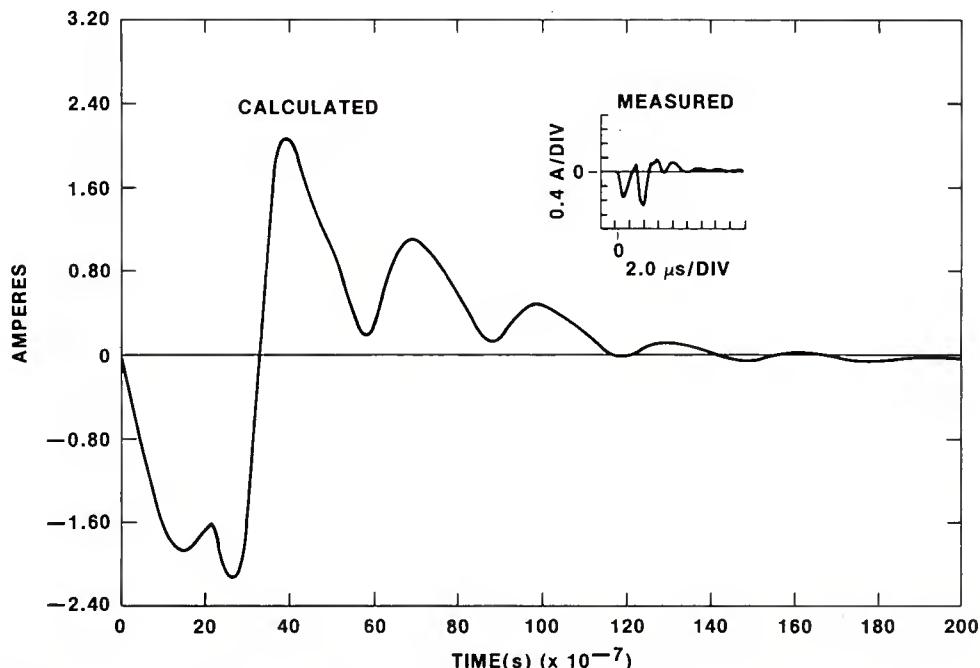

Figure 11.   Current on shields of coaxial cable pair for Radio Set AN/TRC-145 pulse code modulation cable at 4.6 m without ac generator.

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The validation comparisons given so far for the system with the PCM cable have been limited to the exterior current and the coupling to the shields of the two coaxial cables. Since a vulnerability analysis requires the voltage or current response of each coaxial cable, not just the current on its shield, an additional analytical model for this response had to be developed and validated.

Detailed modeling of the coupling through both the external shield and one of the internal coaxial shields was not possible with the available analytical tools since code FREFLD treats only singly shielded cables. However, through shielding effectiveness testing conducted on the PCM cable, it was found that the coupling through the shield of the internal coaxial cable was essentially a resistive effect over the range of frequencies of interest. Therefore, the shield transfer impedance used for calculating the response of coaxial cables was the parallel resistance of the external shield and the two coaxial cable shields. Figure 12 compares the calculated voltage response and that measured during the system field test.

The general wave shapes agree well, but the amplitude differs by about a factor of five. At first glance, this difference may seem poor. But if one considers the approximations that had to be made in the model and the relatively poor simulation that was possible, then it seems reasonable that the calculated responses should tend to be greater.

Also, the fact that the analytical model produces a larger response than may actually occur in the event of an EMP merely makes the system assessment more conservative. The validation of the analytical model with the system level test ensures that the interaction and coupling estimates are not so conservative that protecting the system to the predicted signal levels is not feasible or cost effective.

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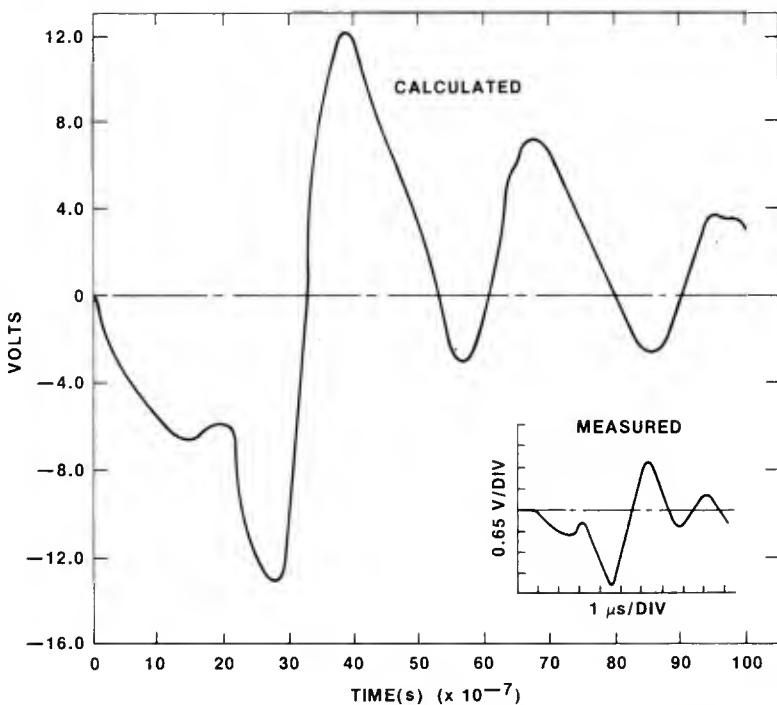
Figure 12. Pulse code modulation cable field test response.

6. CONCLUSIONS AND RECOMMENDATIONS

This preferred prediction method for applying interaction and coupling codes to systems allows greater accuracy in system vulnerability assessments than do programs based solely on analytical or experimental methods of handling the primary interaction and coupling problems. Complex systems similar to the ones in the MSEP can have too many uncertainties to be handled easily by a purely analytical method. These uncertainties might result in such conservative assessments that the protection requirements would be impossible to meet. Moreover, purely experimental assessments involving worst-case simulation with existing simulators are possible for only a few systems. It is important to obtain a good balance between simulation testing of systems and interaction and coupling analysis.

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